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Solar energy: Trends and enabling technologies

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ABSTRACT

The global demand for energy is currently growing beyond the limits of installable generation capacity. To meet future energy demands efficiently, energy security and reliability must be improved and alternative energy sources must be investigated aggressively. An effective energy solution should be able to address long-term issues by utilizing alternative and renewable energy sources. Of the many available renewable sources of energy, solar energy is clearly a promising option as it is extensively available. Solar power, especially as it reaches more competitive levels with other energy sources in terms of cost, may serve to sustain the lives of millions of underprivileged people in developing countries. Furthermore, solar energy devices can benefit the environment and economy of developing countries. This paper illustrates the need for the utilization of alternative energy sources, evaluates the global scenario of installed generation systems, reviews technologies underlying various solar powered devices, and discusses several applications and challenges in this area. In addition, this paper addresses the costs of deployment, maintenance, and operation, as well as economic policies that promote installation of solar energy systems.

Contents

1. Introduction . . . 555
2. Solar technologies . . . 557
   2.1. Solar photovoltaics . . . 557
   2.2. Concentrating solar photovoltaic systems . . . 557
   2.3. Flat plate and evacuated tube solar collectors . . . 557
3. Global scenario and statistics . . . 558
4. Cost of electricity generated from solar systems . . . 559
5. Applications . . . 559
   5.1. General applications . . . 559
   5.2. Approaches to integrated energy solution . . . 560
   5.3. Wireless sensors for improved performance . . . 561
   5.4. Integration into the smart grid . . . 561
6. Economic policies to promote solar energy . . . 562
7. Challenges to solar energy . . . 562
8. Solar in developing countries . . . 562
9. Conclusions . . . 563
References . . . 563

1. Introduction

Preventing an energy crisis is one of the most crucial issues of the 21st century. In the past, there has been a constant endeavor to find an alternate way to satisfy the growing energy needs of the global population – the vast majority still living in poverty – without

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plundering the resources that will be needed by future generations, polluting our ecosystems, and putting undue pressure on the energy-rich regions of the world. In achieving this, the first problem faced is the explosion in demand due to both the rapid increase in population and the efforts of the most densely populated regions of the world to develop their economies. In just one generation, the global population has increased by nearly 2 billion, with a major contribution from developing countries. Also, it is a known fact that energy demand increases at a rate that is proportional to economic growth. Based on this, the International Energy Agency (IEA) estimates that developing countries will need to double their installed generation capacity in order to meet the growing demand for power by the year 2020. In the International Energy Outlook (IEO) 2009 [1], the total world consumption of marketed energy is projected to increase by 44% from 2006 to 2030, as shown in Fig. 1.

In spite of several initiatives, policies, and investments for increasing generation capacity, the number of non-electrified areas in developing countries has not changed significantly. Lack of access to electricity continues to be one of the major reasons that citizens of non-electrified communities are still poor [2]. Therefore, it is critically important to create the required infrastructure and install the needed distributed energy generation resources to satisfy global energy needs.

Renewable energy is not a new concept, but it continues to rapidly emerge as an alternative to fossil fuels and other deleterious energy sources. The potential of renewable energy sources is enormous as they, in theory, can produce many times the world's total energy demand. For example, some studies have indicated that roughly 1000 times the global energy requirement can be fulfilled by using solar energy; however, only 0.02% of this energy is currently utilized [3]. Renewable energy sources such as biomass, wind, solar, hydropower, and geothermal can provide sustainable energy services based on the utilization of routinely available indigenous resources. A transition to renewable energy systems is increasingly likely as their costs continue to decline while the cost of fossil fuels continues to rise. In the past 30 years, solar and wind power systems have continued to improve their performance characteristics and have experienced rapid sales growth. The capital and generation costs associated with such systems have also been reduced significantly. Because of these developments, market opportunities now exist to both innovate and take advantage of emerging markets in order to promote renewable energy technologies, particularly with additional assistance of governmental and popular sentiment. The development and use of renewable energy sources can enhance diversity in energy supply markets, contribute to securing long term sustainable energy supplies, help reduce local and global atmospheric emissions, and provide commercially attractive options to meet specific energy service needs. The use of renewable energy is also becoming increasingly important to slow the effects of climate change.

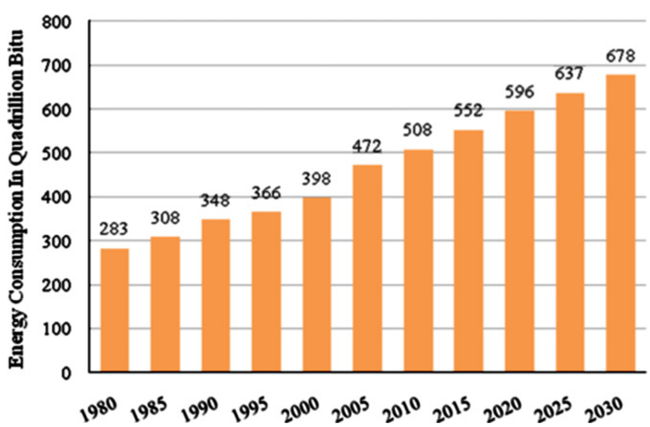

Fig. 1. World marketed energy consumption 1980–2030 [1].

Solar technologies are an extremely promising renewable resource considering their ever-increasing output efficiencies and ability to be utilized in a variety of locations. The intrinsic qualities of solar energy make it a beneficial utility, especially for developing countries, for many reasons: first, most developing countries are located in regions with optimal access to the sun's rays. This is illustrated in Fig. 2. For instance, India's solar power reception is about 5000 trillion kWh per year. In addition, the average radiation in tropical and sub-tropical regions located in developing countries can be compared to that of annual global radiation of about 1600–2200 kWh/m^2 [4]. Second, most of the available fossil fuel and energy resources can only be used by exploiting the ecosystem, which leads to social decline. Third, rising global independence of fossil fuels quickens the need for solar technology, escalates enhancement of required research, and thereby lowers related costs. Fourth, solar systems are relatively affordable and applicable to both homes and villages, as households of industrialized nations are using more solar power than ever before. Finally, within solar technologies, passive solar designs excel when considering renewable energy for buildings, and can be coupled with solar panels to achieve maximum comfort and sustainability.

The remainder of this paper will review the most popular solar technologies, examine the current state of solar globally, discuss the costs associated with the generation of solar power, evaluate various applications of solar power, briefly review policies surrounding solar power, and then conclude.

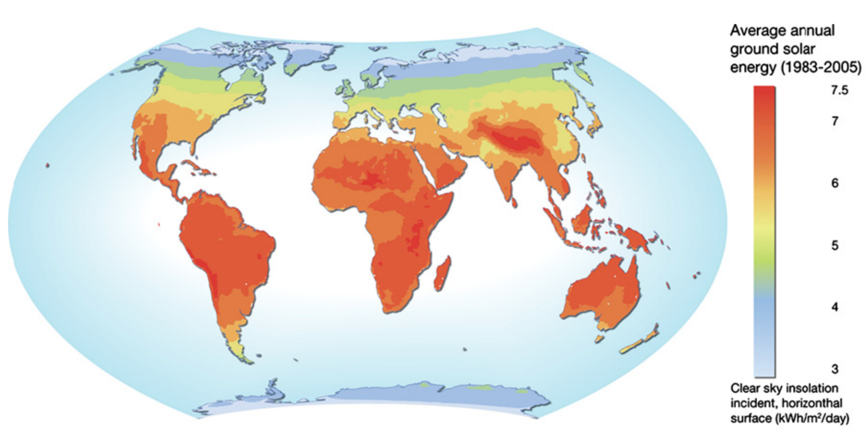

Fig. 2. Average annual global solar energy [4].

2. Solar technologies

Solar energy can be converted into electrical energy using various technologies like photovoltaic (PV) panels, concentrating solar thermal power (CSP), and concentrating photovoltaics (CVT) [5]. The following sub-sections explain these currently available technologies.

2.1. Solar photovoltaics

Solar PV modules are solid-state semiconductor devices that convert sunlight into direct-current electricity. Materials used on PV panels are mono-crystalline silicon, polycrystalline silicon, micro-crystalline silicon, copper indium selenide, and cadmium telluride [6]. PV production has been doubling every 2 years, increasing by an average of 48% each year since 2002, making it the world's fastest-growing energy technology [7]. Roughly 90% of the current generating capacity from PV consists of grid-tied electrical systems. Such installations may be ground-mounted (and sometimes integrated with farming and grazing) or built on the roof or walls of a building, known as building integrated photovoltaics (BIPV). Modern solar PV power stations have capacities ranging from 10 to 60 MW although proposed solar PV power stations will have a capacity of 150 MW or more [8]. Net metering and financial incentives (such as preferential feed-in tariffs for solar-generated electricity) have supported solar PV installations in many countries. A typical PV panel can now operate for up to 10 years at 90% of its rated power capacity and for up to 25 years at 80% of its rated power capacity. Fig. 3 shows the total installed solar energy nameplate capacity and generation for the United States.

PV technologies have been manufactured by many companies that include capital equipment producers, cell manufacturers, panel manufacturers and installers [10]. The list does not include silicon manufacturing companies. According to an annual market survey by the PV trade publication Photon International, global production of PV cells and modules in 2009 was 12.3 GW, and the top 10 manufacturers accounted for 45% of this total [11]. The leading PV manufacturers include First Solar, Suntech Power, Sharp, Q-Cells, Yingly Green Energy, JA Solar, Kyosera, Trina Solar, Sunpower, and Gintech [6]. A brief description of some of these manufacturers includes:

- *Suntech*—Suntech Power Holdings Co., Ltd. is the world's largest producer of crystalline silicon PV modules. As the center for the company's global operations, Suntech Headquarters, in Wuxi, China, features the world's largest building integrated solar facade. Suntech Power is the world's largest producer of solar panels, with 1800 MW of annual production capacity by the end of 2010. Total solar PV cell shipment in 2010 was 1572 MW [12].

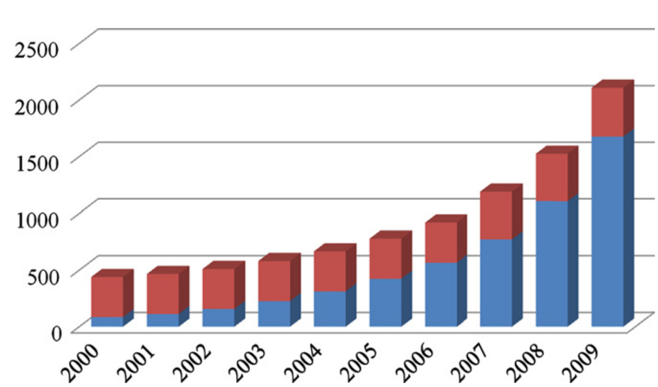

Fig. 3. Graph showing the total installed solar energy nameplate capacity and generation in the US for 2000–2009.

- *JA Solar Holdings*—A Solar Holdings: JA Solar Holdings designs and manufactures monocrystalline solar cells primarily in the People's Republic of China. JA Solar Holdings also sells its products to customers in Germany, Sweden, Spain, South Korea, and the United States. Total solar PV cell shipment in 2010 was 1464 MW [13].
- *First Solar*—First Solar, Inc. is a publicly held US energy company in the solar sector. It manufactures PV solar modules using a thin film semiconductor process based on Cadmium Telluride (CdTe), to produce PV modules. Total solar PV cell shipment in 2010 was 1411 MW [14].
- *Yingli*—Yingli, also known as Yingli Green Energy Holding Company Limited, is a solar energy company and one of the largest vertically integrated manufacturers of photovoltaic solar modules. Total solar PV cell shipment in 2010 was 1062 MW [15].

2.2. Concentrating solar photovoltaic systems

PV panels can sometimes be inefficient in capturing all available energy from sunlight because of their shape and varying solar intensity throughout the day. An alternative way to efficiently capture maximum solar energy is through the use of CSP systems. CSP systems use lenses or mirrors to focus sunlight gathered over a large area into a small area to generate electrical energy. Solar concentrators are mounted on the solar tracker to keep track of the position of the sun. As long as the temperature is at an optimum point for a junction of cells, the solar cells will operate at high efficiency. If these systems are installed at a large solar plant, then they can be used to ensure that the harnessed energy is more effectively converted to heat. Parabolic trough solar thermal systems are the only CSP systems commercially available. These systems use parabolic, trough-shaped mirrors to focus sunlight on thermally efficient receiver tubes that contain a heat transfer fluid. This fluid is heated to about 390 °C (734 °F) and pumped through a series of heat exchangers to produce superheated steam that powers a conventional turbine generator to produce electricity.

Recently, power towers and dish/engine type CSP systems have been developed. Power towers consist of an array of relatively small flat glass mirrors placed around a receiver (solar boiler) which converts the light received into useful heat. These mirrors reflect sunlight onto the collection surface of a solar boiler, which is located on top of a tower. The concentrated sunlight that is focused on the collection surface is used to directly create steam, which then drives a turbine/generator to produce electricity. Some power tower receivers use molten salt as a heat transfer medium to generate steam through heat exchangers (like a parabolic trough). Dish–Stirling is a 25 kW solar power system that has been designed to automatically track the sun and focus solar heat onto a power conversion unit (PCU). This, in turn, converts the intense heat to grid-quality electricity. The concentrator consists of a 38-foot diameter dish structure that supports 82 curved glass mirror facets, each three feet by 4 ft in area. These mirrors concentrate solar energy onto the heater head of a high efficiency, four cylinders, reciprocating Stirling cycle engine generating up to 25 kW of electricity per system. However, these systems are currently under development and thus not available commercially. The main advantage of using CSP, besides its efficiency, is that these technologies involve a thermal intermediary and, thus, can be readily hybridized with fossil fuels and in some cases adapted to utilize thermal storage.

2.3. Flat plate and evacuated tube solar collectors

As opposed to CSP systems, flat plate or evacuated tube solar collectors may be used to gather solar energy in a non-concentrated manner for heating and cooling purposes [16]. Due to their high

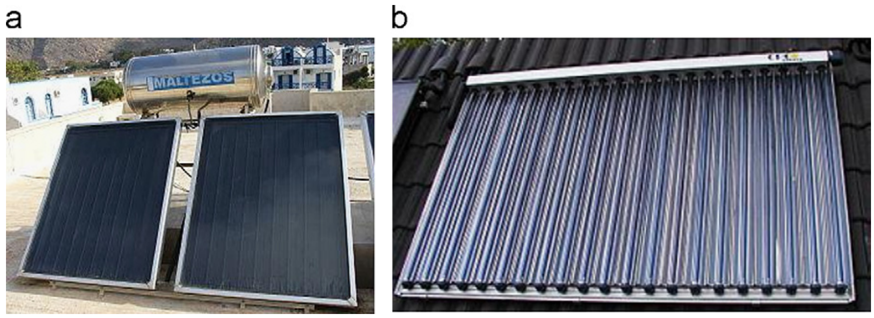

Fig. 4. Examples of flat plate and evacuated tube solar collection systems. (a) An example of a flat plate solar collection system [21]. (b) An example of an evacuated tube solar collection system [22].

efficiency and cost effective nature, this technology is becoming very popular worldwide and may be used year round, even in high humidity, cold temperatures, and/or generally poor weather conditions [17]. Partly due to their increased efficiency over electric water heating [18], as of 2010, over 70 million residences worldwide had active installations of this technology [19,20]. Images depicting both flat plate and evacuated tube solar collectors are shown in Fig. 4.

The basic construction of these systems consists of some type of absorption mechanism, a transfer mechanism, and some type of storage [23]. The absorption mechanism is typically some type of copper tubing in various configurations that are painted with a coating to improve efficiency [24]. Various pipe configurations may include harp, serpentine, completely flooded, or boundary layer [23]. Water or air is circulated through this piping system where it is heated and returned to storage. A more efficient modification of this technology is the evacuated tube collector. In this configuration, heat pipes are vacuum sealed into a containment unit. These pipes are then used to transfer heat using a manifold. The evacuated tube construction is often preferred as it is 20–45% more efficient than flat plate solar collectors, achieves reduced heat loss by mitigating conductive/convective forces via vacuum sealing, uses inexpensive pipes that are durable and inexpensive to replace, and, due to the cylindrical nature of the pipes, tracks the sun passively leading to increased efficiencies at lower costs [25].

3. Global scenario and statistics

The recent advances in technologies that harness solar energy have led to a rapid expansion of the solar energy market. A summary of this growth in the United States is shown in Table 1. In 2010, globally, the increase in the solar PV nameplate capacity was exceptional. New capacity additions were about 17 GW and this addition elevated the total nameplate capacity to 40 GW. In 2010, the total capacity of PV grew by 72% compared to the previous year. The European Union accounts for 13.2 GW of new addition—roughly 80% of global additions. Significantly, Germany accounts for an addition of 7.4 GW, more than any other country. Italy had an estimated addition of 2.3 GW. New PV installations in the Czech Republic were 1.5 GW. Apart from Europe, Japan reported an increase of 1 GW, the USA about 0.9 GW, and China about 600 MW. By the end of 2011, the total installed utility scale solar energy capacity was shared among different countries as follows: Spain 32%, Germany 26%, Italy 16%, the USA 7%, and the Czech Republic 6% [9]. Also, the price of Solar Energy Systems (SES) came-down by 15%, new PV installations grew by 66%, and total revenue increased by 67%, when comparing the first quarters of 2010 and 2011 [26]. However, 10 of the top 15 cell manufacturers in the industry are located in Asia.

Several developing countries are planning for the large-scale development of SES. For instance, the Indian government is actively extending its current solar installations and has planned to install SES units of about 1 GW by 2013, 10 GW by 2017, and 20 GW by 2022 [27,28]. A solar thermal power station is currently being constructed in the Banaskantha district in North Gujarat, India, as part of this project. Once completed, it will be the world's largest solar power station [29]. In August 2009, First Solar announced plans to build a 2 GW PV system in Ordos City, Inner Mongolia, China, in multiple phases of installation consisting of 30 MW in 2010, 970 MW in 2014, and another 1 GW by 2019 [30]. Fig. 5 illustrates the share of PV market by country in 2010.

In 2010, newly installed capacity of CSP increased about 77% compared to 2009. New CSP installations between 2007 and 2010 were about 740 MW with about 478 MW in 2010 alone. At present, total global installed nameplate capacity has reached 1095 MW. Of

Table 1
Total installed solar energy nameplate capacity and generation in the US for 2000–2009 [9].

Year	US Solar Energy Generation (million kWh)	U.S. Solar Energy Capacity (MW) and % increase from previous year			
		PV	CSP	Total	Increase (%)
2000	909	85	354	439	4.30
2001	952	112	354	466	6.20
2002	1021	156	354	510	9.40
2003	1132	226	354	580	13.70
2004	1267	312	354	666	14.80
2005	1444	424	354	778	16.80
2006	1670	566	355	921	18.40
2007	2133	771	419	1190	29.20
2008	2662	1106	419	1525	28.20
2009	3588	1677	431	2108	38.2

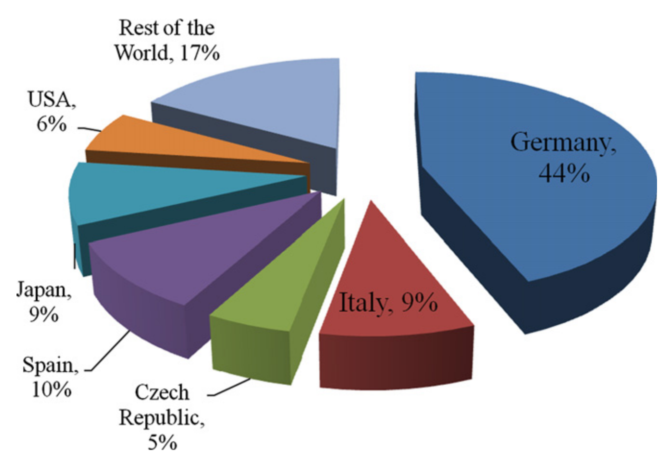

Fig. 5. Share of PV market by country in 2010 [9].

this, Spain added 400 MW in 2010, giving the country a total of 632 MW in operation. In Spain, another 946 MW of CSP is under construction and is expected to be completed by the end of 2013. In the USA, total capacity of CSP is 509 MW with new additions of 78 MW. In addition, several CSP projects are under construction in Australia, China, India, Italy, Mexico, and South Africa.

When considering types of solar heating, the total worldwide installations as of 2010 and 2011 totaled roughly 149 GWth and 185 GWth, respectively [9,31]. The largest installations occurred in China (105 GWth) and the European Union (18.3 GWth) [9,20]. By 2015, Brazil also plans to install roughly 1000 MW of solar heating systems [20]. In the US, most growth has been seen in the area of thermal process heating systems (industrial solar heating) and the heating of swimming pools (a 13% increase) [32].

4. Cost of electricity generated from solar systems

Driven by advances in technology and increase in manufacturing scale and sophistication, the cost of PV cells has declined steadily since the first solar cells were manufactured [10]. Although the cost of electricity produced from PV systems is still higher than the other competing technologies, this cost is expected to continue to decline steadily. The cost of PV installation was $2 per unit of generating capacity in 2009 which came-down to about $1.50 in 2011. According to industry analysis, this price is slated to reach $1 per unit of generating capacity by 2013. These potential reductions in cost, combined with the simplicity, versatility, reliability, and low environmental impact of PV systems, should help PV systems to become highly utilized sources of economical, premium-quality power over the next 20–30 years.

At present, in the USA, the levelized cost of energy from PV is $0.211/kWh and from CSP is $0.312/kWh [33]. Solar electric prices today are at approximately $0.30/kWh, or around 2–5 times the average residential electricity tariffs (the calculation depends on installation location and local electric rates). This is due to the high installation costs involved. Table 2 shows a comparison of the construction cost, operation and maintenance cost, and fuel costs for various sources of electricity generation. In developing countries, SES can provide the basic energy needs of houses in remote and rural areas at a fraction of the cost spent on traditional electricity. Thus, the cost of electricity from PV systems is relatively cost effective. Demand for solar powered systems is very high in countries with high electricity tariffs. Fig. 6(a) shows the improvement in affordability of both solar thermal and solar PV systems. Fig. 6(b) illustrates the current electricity costs of generation using various major renewable energy sources.

Table 2
Estimated levelized costs of new generation sources in 2016 [33].

Plant type	Levelized capital cost ($/MWh)	Transmission investment ($/MWh)	Total system levelized cost ($/MWh)
Conventional coal	65.5	1.2	95.1
Natural gas (combined cycle)	17.5	1.2	65.1
Wind (off shore)	209.7	5.9	243.7
Concentrated solar power	259.8	5.8	312.2
Solar—photovoltaic	194.9	4.0	211.0

5. Applications

5.1. General applications

This section reviews some applications of SES:

- *Building-integrated photovoltaics*: Building-integrated photovoltaics (BIPVs) are a promising option for households in remote, mountainous, and rural areas with no access to the electric grid, as arrays of PV panels are mounted on the roof or the external walls of buildings [34]. Zero energy solar houses, where energy required by the household appliances is generated by the solar panels at the same premises, could be another option. In case the energy generated at such houses exceeds the total household energy consumption, the surplus energy can be fed back to the utility grid [35].
- *Crop and grain drying*: The use of solar dryers in agriculture can prove to be extremely efficient due to the low manufacturing and operating cost. Solar dryers are able to protect grain and fruit, dry faster and more uniformly, and produce a better quality product than open-air methods.
- *Greenhouse heating*: Solar greenhouses utilize solar energy for both heating and lighting. A solar greenhouse equipped with thermal mass can be used for collecting and storing solar heat energy. The greenhouse can also be insulated to retain this heat for use during the night and on cloudy days. This will greatly reduce the need to use fossil fuels for heating. A gas or oil heater may serve as a backup heater or to increase carbon dioxide levels inside the greenhouse in order to induce higher plant growth.
- *Heating and cooling*: Technologies like flat plate and evacuated tube solar heating and cooling are currently being used in multiple applications. These include solar water heating systems for commercial/residential use, the heating of swimming pools, and solar air heating systems.

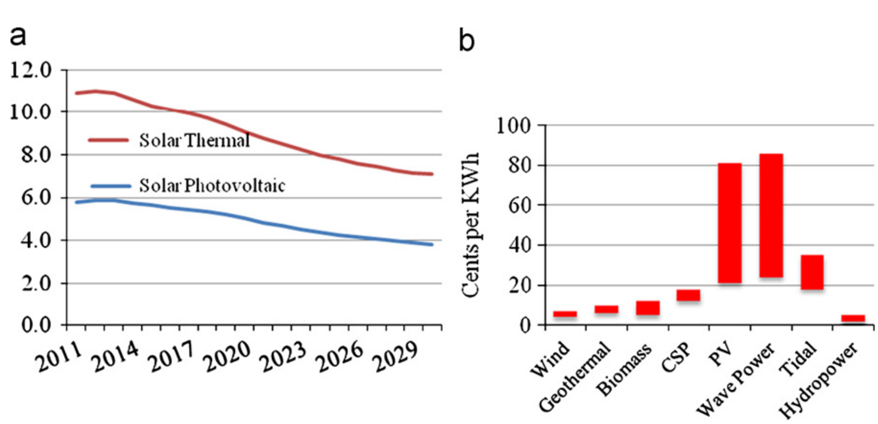

Fig. 6. Capital and generation costs for various sources. (a) Projected average installed capital costs for new solar electricity generating plants [1]. (b) Costs for generating electricity for various non-renewable sources.

- *Micro-scale applications*: On an even smaller level, an integrated micro power generation solution would eliminate the need to plug low power systems into the AC mains for primary power or for battery recharging or replacement and disposal. In addition, whereas outdoor solar energy has the capability of providing a power density of 15,000 W/cm^3, its power density drops down to as little as 10–20 W/cm^3 for indoor applications [36]. Roughly, a 100 mm^2 PV cell under office lighting yields approximately 100 mW of power [37,38]. Applications to date include contact and motion sensors for building applications [39], as well as calculators, PDAs, and wristwatches [37].
- *Remote electricity supply*: PV systems convert sunlight directly to electricity. They can power an electrical appliance directly or store solar energy in a battery. A "remote" location can be several miles or as little as 50 ft (15 m) from a power source. SES may be much cheaper than installing power lines and step-down transformers in applications such as electrical fencing, lighting, and water pumping.
- *Water pumping*: Although current prices for PV panels make most crop irrigation systems impractical, PV systems are very cost effective for remote livestock water supply, pond aeration, and small irrigation systems. Also, PV water pumping systems may be the most cost-effective water pumping option in locations where there are no existing power lines.

5.2. Approaches to integrated energy solution

In addition to solar energy, there are several other well-known macro-level renewable energy sources such as wind, geothermal, bio-energy, and hydropower, which can be integrated on a grid-level. However, for smaller meso-scale or off-grid energy generation, options for non-solar power generation are limited. Small wind energy converters or turbines ranging in size from 20 W to 100 kW are available, enjoying a 78% market growth in the US in 2008 [40,41]. Available in many parts of the world, annual average wind speeds of 3–4 m/s (7–9 mph) can be adequate for these small wind generators. With power outputs between 5 and 100 kW, micro-hydro generators are used to power small communities, residences, or small enterprises, usually in remote mountainous regions [42]. Pico-hydro power generation systems have outputs below 5 kW and are usually used for one to three residences. Often these can be integrated with biodiesel generators or wood stoves to develop an integrated meso-scale solution.

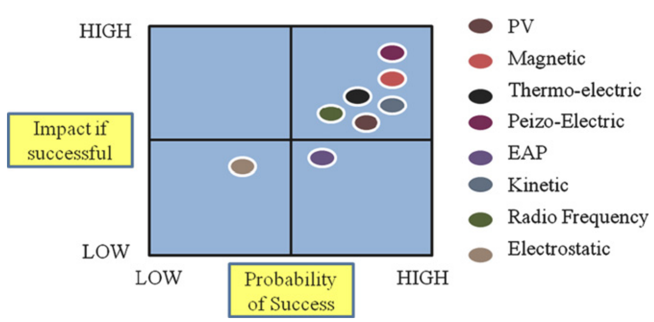

Fig. 7. Frost & Sullivan's opportunity analysis matrix of various micro energy harvesting technologies [30].

For embedded applications, it is obvious that solar energy is unavailable. Other micro-renewal energy sources have greater potential for various indoor, embedded, or remote environments, including vibration, magnetic, heat differential or thermal, and kinetic energy harvesting. Mechanical vibrations and air flow are the other most attractive alternatives [42–44]. Vibrational energy harvesters may utilize electromagnetic, magnetostrictive, electrostatic, or piezoelectric technology. As piezoelectric-based technologies have proven to be a high volume manufacturing success, a National Science Foundation (NSF) workshop considered these harvesters mature and adequate. Likewise, Frost & Sullivan concluded that they have the highest probability and impact of success, as shown by their opportunity analysis in Fig. 7 [45]. These harvesters are being evaluated for the powering of sensor nodes for wireless sensor networks, controllers, data loggers, data processors, low power and portable electronics, transmitters, and possibly cell phones and LED lighting. Fig. 8 shows that these harvesters are addressing the convergence of technology and market trends towards ubiquitous, wireless, "smart" sensing, controlling, and operations.

Vibrational energy harvesters use wasted and often unwanted vibrational energy to generate usable electrical power for the low-power device and system market. As shown in Table 3, harvestable vibrational energy is available nearly everywhere, including civil structures (bridges and pipelines), transportation vehicles (airplanes, cars, trucks, and even bicycles), roads (traffic), industrial or mechanical equipment (air compressors, handling equipment, pumps, rotating machinery, and HVAC equipment), and even from wind and footfalls. For machine powered applications, Mitcheson estimated vibrational power densities were closer to 800 W/cm^3 [46]. Starner showed a 68 kg human produces 67 W of energy at the heel walking at 3.5 mph or two steps per second. The theoretical limit for power

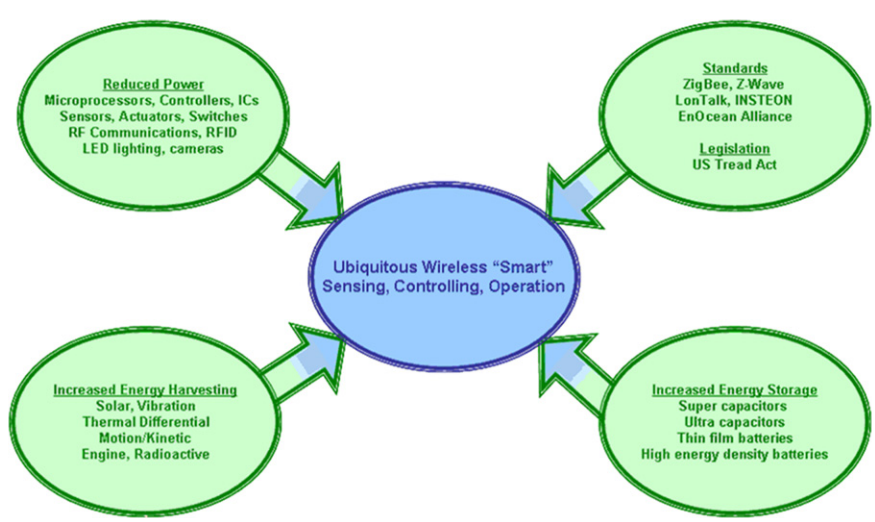

Fig. 8. Recent technology and market trends enabling ubiquitous, wireless, 'smart' sensing, controlling, and operations.

generation from walking has been determined to be 1.265 W daily [47]. In order for energy to be harvested from walking, vibrational energy harvesters may be installed in shoes or under a floor or walkway. The East Japan Railway Company (JR East) conducted a demonstration experiment from 19 January to 7 March 2008, at Yaesa North Gate, Tokyo Station, on a new power-generating floor installed at the ticket gate area, shown in Fig. 8. JR East expects to generate enough electricity to light a 100 W bulb for about 80 min per day. It intends to use the power for station facilities such as automatic ticket gates or electric displays in the near future. Club Surya in London and Club Watt in Rotterdam are the first of the latest eco-nightclubs utilizing power generating floors, recovering 30% and 10%, respectively, of the dance clubs' electrical requirements.

Table 3
Potential vibration sources for energy harvesting.

Human body	Breathing, blood pressure, exhalation, walking, arm motion, finger motion, jogging, swimming, eating, talking
Vehicles	Aircraft, UAV, helicopter, automobile, trains, tires, tracks, peddles, brakes, shock absorber, turbines
Structures	Bridges, roads, tunnels, buildings, pipelines, oil rigs, control switch, HVAC
Industrial	Motors, compressors, chillers, pumps, fans, conveyors, vibrating machinery
Environment	Wind, ocean currents, waves

Fig. 9. Power generating floor demonstrated by JR East at Yaesa North Gate, Tokyo Station.

Currently, Micro Electro Mechanical Systems (MEMS) and conventional vibrational energy harvesters have been developed at microwatt (μW) and milli-watt (mW) power levels, limiting their usage to powering MEMS sensors, ultralow power wireless sensors, or ultralow power electronic devices.

5.3. Wireless sensors for improved performance

Operation of a solar power plant depends on a number of factors, including electrical (e.g. PV efficiency, output power, temperature etc.), environmental (e.g. intensity of sunlight, direction, rain, air temperature, etc.), and mechanical (e.g. size of the panels, position, incline angle, etc.). The environmental factors play a very crucial role in determining the output from a solar power plant. For example, the direction and orientation of PV panels must be perfect in order to achieve the maximum power output. There is also a need to develop models that will serve as a tool to help identify design barriers and quantify the cost and mass impact of design changes on various components of the solar panels. Using advanced wireless sensors to collect data on PV installations and performing analysis to further enhance system design can be highly attractive to design engineers and researchers (Fig. 9).

A wireless sensor network enables the sensors to be placed all over a structure. Such a wireless system could be combined with electrical, mechanical and environmental monitoring sensors to be a part of a remote, multi-panel, centralized plant monitoring, and control system. Data from the sensors are transmitted via wireless technology to a central monitoring station using satellite Internet as shown in Fig. 10. At the central monitoring station, data is analyzed and a relationship between various sensed parameters is established for improving the efficiency of the whole system. For example, various performance monitoring systems consisting of sensors and other photo-operated devices like op-amp 741 circuitry, photo-transistors, photo sensors, etc., can be integrated into the PV module to enable automatic orientation of the PV module to the sun's direction, making troubleshooting and maintenance more efficient. Efficient energy conversion is possible if the PV modules are equipped with advanced tracking and optical systems (e.g. Fresnel lens).

5.4. Integration into the smart grid

The present electric grid is becoming congested due to a lack of its ability for expansion and continued growth in electricity

Fig. 10. Wireless communication using satellite Internet.

demand. The present electricity grid is non-uniform and unintelligent as the demand side cannot communicate with the supply side. Compatibility of the grid with distributed power supplies would bring down costs for connecting renewable energy sources to the grid. Getting the electricity from the renewable energy sources located in remote areas involves more than just building more power lines. The electric grid should be able to handle greater and faster changes to load flow caused by intermittent generation and should plan for standby reserve capacity to supplement intermittent generation. Effective grid management can be achieved by improving data collection, using efficient communication protocols and network monitoring systems that provide operators with up-to-date information about the status of grid. The smart grid helps to identify faults in the grid and deal with them before they are serious [48]. A smart grid applies state-of-the-art technologies and techniques to make the grid more efficient and provides advanced energy management techniques and approaches for integrating wind or solar power into the grid. The grid's software uses stochastic prediction algorithms for renewable energy forecasting, and such predictions may be used to switch on/off the loads. Smart grids will integrate weather reports, real-time output monitoring, and grid-load balancing to respond to this variability pro-actively [49].

Solar power is an intermittent source of energy, meaning that it may not always be able to meet peak load requirements. As a result, solar energy has to rely upon other expensive energy storage technologies like compressed air, batteries, pumped hydro, etc. One possible solution is to combine plug-in hybrid electric vehicles (PHEVs), smart grids and solar power. A PHEV can be considered as a complimentary resource to provide energy storage during the day. As a result of integrating PHEVs into the smart grid, the PHEV owners benefit by selling energy to the grid during the day when the demand is higher and buying back the energy during the night when the cost is less if a variable-cost electric power system is available. Thus, the solar energy systems and PHEVs result in better economic and environmental benefits when used in conjunction.

6. Economic policies to promote solar energy

The PV market is currently being driven by subsidies, tax exemptions, and other financial incentives. Micro-finance Institutions, which are the most likely funding sources in rural areas, are being supported by bigger government funding agencies. Currently, in the US, the Department of Energy (DOE) uses a systems-driven approach for the management of research activities of SES. This approach uses market analysis, modeling, testing, and prioritizing to determine the research needs and assess progress [50]. In India, Jawaharlal Nehru National Solar Mission has been established to make the necessary changes to government policies in order to promote and develop solar technologies. Changes in policy include making the utilization of solar heaters mandatory, ensuring certification for manufacturers of solar powered appliances, supporting promotion of the SES through local agencies and power utilities, and supporting technological upgrades to achieve high efficiency and cost reduction [27,51].

The ability to promote a clean power source and improve basic living standards is the major attraction for international funding of solar energy in developing countries. Developmental aid funding from several multi-lateral and bi-lateral aid agencies specifically include solar activities, which has benefited the market [52]. Major PV projects valued at tens of millions of dollars have installed and operated in remote villages, in countries such as Indonesia and the Philippines. Increasingly, solar power is being used for programs which develop education, water supply, and healthcare in these countries. Since the initial costs of installing a PV system are very high, and despite lifetime economic advantages, micro-finance is becoming more of a focus in improving its affordability. Kenya is the most notable developing nation with a strong unsubsidized market, where their customers can obtain low power (10–20 W) and entry level PV modules.

7. Challenges to solar energy

Fundamental challenges faced by SES are the cost, manufacturing procedure, and waste products. In order to implement SES at a large scale, technology needs to be cost effective compared to fossil fuel or nuclear energy based generation systems. In addition, educating customers about the advantages and marketing the solar energy products can be expensive and difficult in rural areas, due to low literacy rates. Impractical political promises or plans for rural electrification can also be a barrier for market expansion [53]. Power generation using SES is weather-dependent and the trend of generation cannot be fully predicted. Because of intermittency in power generation, SES might not be a good choice for a continuous load requirement, and raises reliability and power quality issues. Because of this, SES has to be operated in conjunction with the utility grid or some kind of energy storage in order to achieve required continuity in power supply. The grid-connected operation leads to another set of issues related to voltage stability, reactive power demand, etc. Another problem associated with using SES is that the energy generated by the solar energy systems is DC, which has to be converted to AC before utilizing it for home appliances or before feeding it back to the utility grid. Solar energy devices produce no air or water pollution and no greenhouse gases, but do have some indirect impacts on the environment. For example, there are some toxic materials and chemicals, and various solvents and alcohols that are used in the manufacturing process of PV cells. In addition, large solar thermal power plants can harm ecosystems if not properly managed. For example, birds and insects can be killed if they fly into a concentrated beam of sunlight, such as that created by a "solar power tower." CSPs also use potentially hazardous fluids (to transfer heat) that require proper handling and disposal. The use of CSP on a large scale could also lead to water pollution since water is required for regular cleaning of the concentrators and receivers and for cooling the turbine-generator.

8. Solar in developing countries

The main role of all types of solar power in developing countries is twofold: easing the burden of energy production for everyday tasks and lessening the carbon emissions of developing economies. Pursuing these goals will aid in reducing poverty and increasing the general well-being of individuals in these countries [54]. As an example, 30–40% of energy is typically spent on water heating that is done by hauling/burning wood or other fossil fuels [54]. The addition of a solar powered water heating system would lead to increased freedom from this burden (leading to opportunities to pursue other ventures) and increased hygiene due to installed plumbing [54]. Due to these obvious benefits of solar installations in developing countries, much work has been completed regarding general policy [28,55–59] and viability [56,60,61] while also heavily investigating individual locations [28,62,63]. While this work is extensive, it can be summarized in by considering a few main issues: (1) the use of solar in developing countries is highly beneficial in terms of independence, health, and economic growth, (2) governments need to put policies in place that attract investment and encourage

development of this sector, and (3) solar, in general, is an excellent option for developing countries due to their access to high levels of sunlight.

9. Conclusions

Solar power is proving to be an attractive opportunity in terms of both business and power generation. Significant improvements have already been accomplished by numerous international, governmental, and non-governmental organizations including the funding and development of projects involving renewable energy systems for various developed as well as developing nations. This progress is transforming uninhabitable conditions into quality living spaces and providing new luxuries to those who were once lacking. Ecosystems, developing societies, and the solar energy market will only benefit from an increase in solar PV system installations. Funding for these systems, however, is a challenging aspect when considering the widespread demand. Fortunately, as more and more organizations volunteer their financial, professional and technical services, solar energy is becoming more cost effective.

While progress has been slow but steady over the last two decades, the current efforts of industry leaders and researchers have greatly reduced costs and improved efficiencies, thus increasing the demand for SESs. As the price of solar continues to drop amidst the rising cost of fossil fuels, the next decade is sure to see solar power as a primary, integrated, and cost-effective power source that reduces environmental impacts and increases energy security.

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